THEORETICAL UNCERTAINTIES IN HIGGS SEARCHES

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In this talk, we respond to the comments and criticisms made by the representatives of the CDF and D0 collaborations on our recent papers in which we point out that the theoretical uncertainties in the Higgs production cross section have been largely underestimated and, if properly taken into account, will significantly loosen the Tevatron Higgs exclusion bounds. We show that our approach to the theoretical uncertainties is fully justified and, furthermore, provide additional details on our statistical analysis of the CDF and D0 exclusion limit which show that it is conceptually correct.

1 Introduction

In two earlier papers[1,2], we updated the theoretical predictions for the production cross sections of the Standard Model Higgs boson at the Tevatron collider, focusing on the main search channel, the gluon–gluon fusion mechanism $gg \to H$, including the relevant higher order QCD and electroweak corrections[3]. We then estimated the various theoretical uncertainties affecting these predictions: the scale uncertainties which are viewed as a measure of the unknown higher order effects, the uncertainties from the parton distribution functions (PDFs) and the related errors on the strong coupling constant α_s, as well as the uncertainties due to the use of an effective field theory (EFT) approach in the determination of the radiative corrections in the process at next-to-next-to-leading order (NNLO). We found that contrary to the Higgs–strahlung processes[3], where the rates are well under control as the uncertainty is less than $\approx$ 10%, the theoretical uncertainties are rather large in the case of the gluon–gluon fusion channel, possibly shifting the central values of the NNLO cross sections by up to $\approx$ 40%. These uncertainties are thus significantly larger than the $\approx$ 10%–20% error assumed by the CDF and D0 experiments in their analysis that has excluded the Higgs mass range $M_H = 158$–175 GeV at 95% CL[4,5]. As $gg \to H$ is by far the dominant Higgs production channel in this mass range, we concluded that the above exclusion limit should be reconsidered in the light of these large theoretical uncertainties.

After our papers appeared, some criticisms have been made by the members of the CDF and D0 collaborations and of the Tevatron New Physics and Higgs working group (TevNPHWG)[6] concerning the theoretical modeling of the $gg \to H$ production cross section that we proposed. This criticism was made more explicit at this conference[7]. In this note, we respond to this criticism point by point and show that that our approach to the theoretical uncertainties is fully justified. In particular, we will make use of of a recent collective effort[8] made by theorists along with experimentalists of the ATLAS and CMS collaborations to evaluate the Higgs cross section at the LHC, with a special attention to the gluon fusion mechanism which is also the process of interest here. Several issues discussed in our papers[1,2] have been indeed addressed in the report of this working group. It turns out that many of the proposals that we put forward for the $gg \to H$ process are in fact similar to those adopted in this comprehensive LHC study. We will thus also use the conclusions of this report (together with other studies that appeared meanwhile) to strengthen some arguments even more.

Another criticism made by the CDF and D0 collaborations is on the statistical analysis of the exclusion limit that we performed in Ref. [2], using the detailed information and the multivariate analysis given in a CDF paper [5]. Apparently, there was a misunderstanding on what we actually did in our "emulation" of the CDF/D0 limit: we did not increase the theoretical uncertainty (or add an extra uncertainty) but simply changed the normalisation as if the cross section was evaluated using another PDF set (such as HERA[9] or ABKM[10] rather than the adopted MSTW choice[11]). In this case, using the neural network output of the CDF analysis to re-estimate the sensitivity and the exclusion limit is fully justified and our analysis is conceptually correct.

Finally, we take this opportunity to correct an error made in Ref. [2] in the numerical evaluation of the $gg \to H$ cross section using the HERA PDF set [9]. This error will only slightly change part of the discussion in Ref. [2] and will not alter our general conclusions.

2 Summary of the answer to the criticisms

A detailed answer to these criticisms has recently appeared on the arXives [12]. Because of the lack of space, we will simply summarize here the main points that we put forward in our analysis of the $gg \to H$ cross section at the Tevatron and refer to Ref. [12] for the details.

2.1 Discussion of the theoretical uncertainties in the NNLO production rate

i) The scale uncertainty has not been overestimated in our analysis. We gave several arguments in favor of an extended domain for scale variation and in fact, it turns out that our uncertainty is comparable to that assumed by the CDF/D0 collaborations when the $gg \to H$ cross section is broken into jet cross sections and to the (even larger) uncertainty advocated in Ref. [13] when the impact of the jet veto is included in the Higgs+0 jet cross section alone.

ii) For the uncertainty from the EFT approach, many of its components have been discussed in other papers such as Ref. [8] and we simply made the effort to quantify the overall impact.

iii) We do not believe that we are overestimating the PDF uncertainties. In fact the result that we quote within the MSTW set is exactly the one that is obtained used the PDF4LHC recommendation[14]. We even believe that we are underestimating these PDF uncertainties, especially if the analysis of Ref. [15] turns out to be correct. In particular, the difference between the MSTW and ABKM predictions of 25–30% (which is the most significant one[a]) is still larger than our PDF uncertainty within the MSTW set, see the left-hand side of Fig. 1.

iv) We do not add linearly the PDF and scale+EFT uncertainties. Our procedure, which has been also advocated in other analyses like Ref. [16] for top-quark pair production, addressed also the theoretical part of the uncertainties. The result that we assume is indeed close to a linear sum (in fact slightly smaller), but a linear combination of scale+PDF uncertainties is exactly the one recommended in the LHC Higgs cross section working group report[8].

v) If the recommendations of the LHC Higgs cross section working group report [8] are adopted for the CDF uncertainties, one would obtain the same uncertainties as the ones that we are advocating in the paper (modulo the small EFT uncertainties); see the right-hand of Fig. 1 where the total uncertainties of various calculations are displayed.

vi) The various issues discussed here appear also in the case of Higgs production in supersymmetric extensions of the Standard Model. The theoretical uncertainties turn out to be also quite large in the main production channels [17], $gg + b\bar{b} \to$neutral Higgs$\to \tau^+\tau^-$.

[a]This is different from what we claimed previously as we had a numerical error in the cross section when evaluating it with HERAPDF which led to a 40% difference. We thank Graham Watt for pointing this to us.

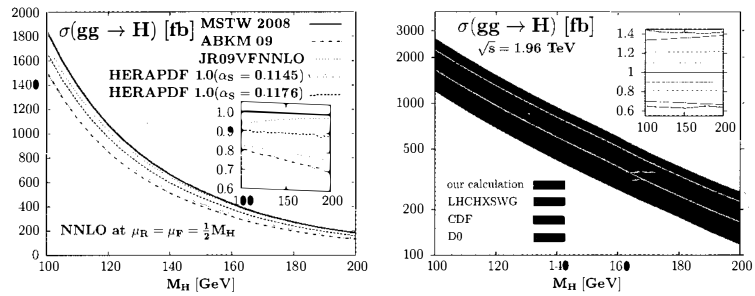

Figure 1: Left: The $gg \to H$ cross section as a function of M_H when the four NNLO PDF sets, MSTW, ABKM, JR and HERAPDF are used. Right: $\sigma_{gg\to H}^{\rm NNLO}$ at the Tevatron using the MSTW PDFs, with the uncertainty band when all theoretical uncertainties are added as in Ref.[1]; it is compared the uncertainties quoted by CDF and D0[4] as well as the one when the LHC procedure[8] is adopted. In the inserts show are the relative deviations.

2.2 *Emulation of the CDF limit calculation*

i) The PDF effect is not included as being a new source of systematic uncertainty but, rather, as a different choice for the PDF set from the CDF one[5], and which affects only the cross section normalisation. Thus, our goal was not to re-estimate the CDF sensitivity but the relative variation of the sensitivity when the cross section is changed by a different PDF choice.

ii) Our results are robust regarding the systematic uncertainties and their correlations, since we are using the multivariate outputs of the CDF analysis that include them.

iii) Our main results for the needed luminosity to recover the present sensitivity agree with estimates obtained in a simple and heuristic way; we believe that this agreement provides a nice check of our analysis. Note however, that we based our analysis on a 40% reduction of the $gg \to H$ cross section when using HERA PDFs. The correct figure with a reduction of only 30% as obtained with ABKM is shown in Fig. 2; this does not change our general conclusions[b].

iv) It is highly desirable that the CDF and D0 collaborations provide us with a fully cut-based analysis which will be easier to follow and reinterpret; we will be more than happy if they could simply redo our analysis in Ref.[2], assume a different normalisation of the production cross section and reinterpret the Higgs mass limit.

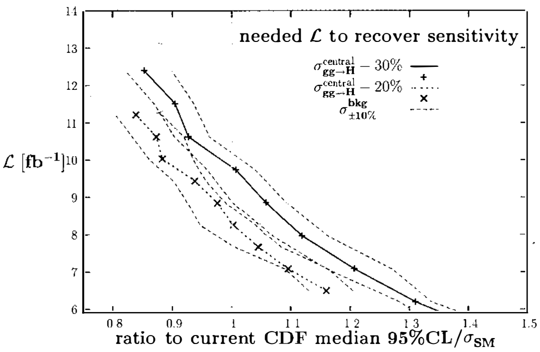

Figure 2: The luminosity needed by CDF to recover the current sensitivity (with 5.9 fb^{-1} data) when the $gg \to H \to \ell\ell\nu\nu$ signal rate is lowered by 20 and 30% and with a $\pm 10\%$ change in the $p\bar{p} \to WW$ background.

[b]This is particularly true as the updated results given by the CDF/D0 experiments at this conferences with 7.1 fb^{-1} data for CDF, lead to an exclusion limit that is slightly worse than the one quoted in Ref.[2] and only the range $M_H = 158$–173 GeV is excluded. Thus, even for a 30% reduction of the production cross section only instead of the 40% used earlier, one still needs ≈ 13 fb^{-1} data to recover the sensitivity obtained with 7.1 fb^{-1}.

2.3 The impact of different PDF parameterizations

Finally, concerning the discussions on the HERAPDF and ABKM parameterizations, let us stress again that they provide reasonable fits to the Tevatron jet data, contrary to an apparently common belief. There are issues about the PDF fits that need more investigation (in particular the point raised recently on the treatment of the NMC data which might lead to a significant impact) and until a better understanding of the large differences between the results of the various sets, one should use the ABKM and HERAPDF predictions as a reflection of the theoretical uncertainty in the game. This is very important since, except from MSTW, they are among the few other parameterizations which are available at NNLO, i.e. the order required to address Higgs production at hadron colliders. It is thus imperative that one assesses the impact of using these two sets for the Higgs production cross section. This is particularly important for a crucial issue such as the exclusion of the Higgs boson in a certain mass range.

3 Conclusion

In view of the above arguments (which have been detailed in Ref. [12]), we strongly believe that the analysis that we have developed in ours papers[1,2] is scientifically sound. It could appear at first sight that we have been a little bit conservative in the estimate of the theoretical uncertainties (although recent analyses tend to show that it is far from being the case), but when it comes to a such a crucial issue as excluding the Higgs boson (which we believe is the most important issue in today high-energy physics), it is more recommended than, to the opposite, being too aggressive. A too optimistic analysis that excludes a possibility that can be discovered somewhere else, would affect and alter the credibility of our field.

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